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# Importance of EMT-Type Simulations for Protection Studies in Power Systems with Inverter-Based Resources

## 1. INTRODUCTION

Inverter-based resources (IBRs) have been increasingly applied in several countries, challenging protection schemes [1],[2]. As a result, the need for reliable simulation and testing platforms capable of properly representing IBRs during protection studies has been highlighted. In the past decades, high inertia systems were predominant, so that phasor-domain simulations used to be considered sufficient for protection assessment. However, phasor-domain models are usually simplified, resulting in inaccurate representation of IBRs under transient conditions. Thus, considering the need for detailed modeling of IBRs in protection studies and researches, Electromagnetic Transients (EMT) programs (EMTP) gained importance, although there are still doubts about the criteria that must be used to justify the use of EMTP rather than conventional phasor-domain short-circuit programs.

## 2. GOAL

Explain differences between phasor-domain and EMT-type simulations, that can justify the use of EMTP platforms for protection studies in power grids with IBRs.

## 3. PHASOR-DOMAIN VERSUS EMT-TYPE SIMULATIONS

As reported in [3], EMTP are capable of simulating a wideband frequency spectrum by solving differential equations via numerical solutions. Hence, small time-steps are required to guarantee such a time resolution, leading the computing time to be high and the initialization of IBR controls to be time consuming. Despite these issues, EMTP allow detailed grid and control modeling, including the detailed representation of Phase-Locked Loop (PLL) schemes and traveling waves, which have driven new protection developments for power systems with IBRs. On the other hand, phasor-domain simulations focus on the fundamental frequency component only. Thus, large time steps can be used, significantly reducing the simulation computing time. Also, the system initialization is simpler than in EMTP. However, grid and control models (including PLL) are often oversimplified [3], which can result in an inaccurate representation of IBRs behavior under fault conditions. Obviously, using EMTP does not necessarily mean that IBRs are accurately represented (it depends on the considered level of modeling details), but EMTP are those which allow the representation of IBR under transient events, whose proper simulation is of utmost importance for protection performance studies.

## 4. IBR TRANSIENT EVENTS WHICH CAN AFFECT PROTECTION FUNCTIONS

In power systems with IBRs, there is a variety of transient events that can affect protection functions. Some of the most important ones are:

- IBR inverter power switching yields distortions in output signals, which are not completely eliminated by IBR terminal filters and transformers [2]. These spurious frequencies may pose difficulties to phasor estimation filters, affecting the protection performance.

- In typical grid following IBRs, PLLs analyze voltages to obtain information about the grid frequency. Since IBRs are weak sources, relevant undervoltage is typically observed during faults, posing difficulties to PLLs. Hence, errors in the estimated frequencies can take place, resulting in frequency deviations in output currents, which can influence phasor-based protection elements.

- Crowbar is used to protect converters applied in Doubly-Fed Induction Generators (DFIG). When the crowbar operates, it short-circuits the converter, leading the IBR (DFIG) to operate as a typical induction generator. Thus, if a DFIG unit is operating with high slips and the crowbar operates, the frequency of output currents can significantly deviate from the grid frequency [1], jeopardizing the performance of phasor-based protection functions.

The abovementioned events are transient in nature, and therefore, they can be simulated only in EMTP platforms. To demonstrate the importance of EMT-type simulations during protection studies in power systems with IBRs, the test power system shown in Figure 1 is simulated. A distance relay is assumed to be installed at the local bus, and faults at different points (F1, F2, F3, …) are tested. The obtained results are shown in Figure 2. Figure 2(a) depicts the distance protection element behavior considering a conventional synchronous generator, and full converter wind power plants (type IV) which operate according the European Grid Code (EGC) reported in [4] and the American Grid Code (AGC) reported in [5],[6]. Also, an example of crowbar operation in a DFIG unit (type III) is presented in Figure 2(b).

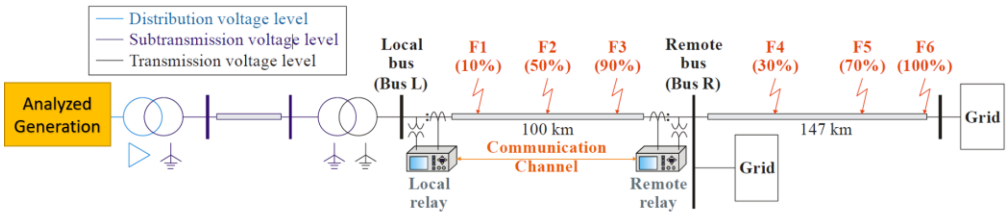
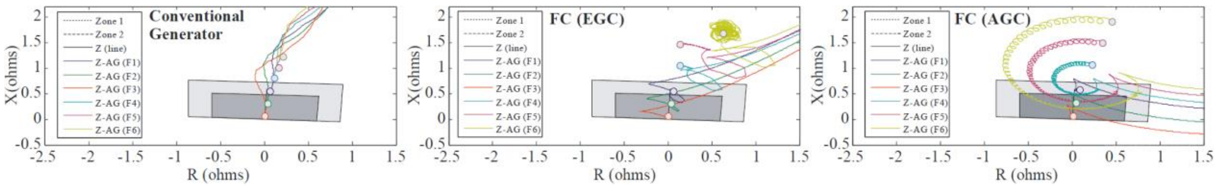
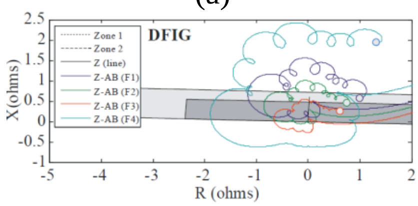


Figure 1: Test power system used for EMT-type simulations.



(a)



(b)

Figure 2: Distance protection behavior for: (a) Faults at different locations, for different generators and grid codes; (b) Example of crowbar operation influence on distance protection element.

It can be noticed that the impedance seen by the relay presents a well-behaved trajectory when conventional synchronous generation is applied. Since the impedance rapidly converges to its steady-state point, it would not be critical for protection performance, such that phasor-domain simulations would be acceptable in this case. On the other hand, when IBRs are taken into account, the impedance trajectories are badly behaved, which can result in protection malfunction. These issues are caused by the previously explained transient events, which cannot be represented by phasor-domain simulations.

## 5. CONCLUSIONS

The presented results attest that EMT-type simulations are essential for protection studies and developments in power grids with IBRs. Indeed, there are IBR transient events which cannot be properly represented in phasor-domain simulation, especially those regarding the presence of non-fundamental components in monitored signals. Even so, using EMTP result in computational challenges, and many platforms are devoid of standardized IBR models. Thus, contributions in EMTP platforms providing accurate open-source standardized IBRs models are of utmost importance.

## 7. REFERÊNCIAS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